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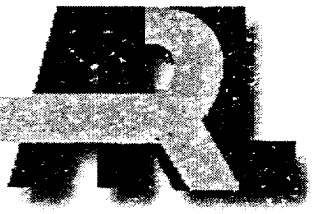

Assessment of Crew Workload for the RAH-66 Comanche Force Development Experiment 1

David B. Durbin

ARL-TN-183 OCTOBER 2001

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ARL-TN-183 October 2001

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Abstract

Crew workload was assessed during the RAH-66 Comanche Force Development Experiment (FDE) 1. The purpose was to determine if (a) the pilots experienced tolerable and comparable workload levels when flying the aircraft versus operating the mission equipment package (MEP), and (b) workload levels contribute to a need to "battle roster" Comanche pilots. Workload data were collected via the Bedford Workload Rating Scale and a cockpit controls and displays usability questionnaire.

Results of the assessment indicate that (a) workload was tolerable for the pilots, (b) workload was moderately higher for the pilots when they operated the MEP, and (c) there is no compelling need to prescribe battle rostering because pilots experienced only moderate differences in workload when they flew the aircraft versus when they operated the MEP.

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Executive Summary

An assessment of crew workload was conducted during the RAH-66 Comanche Force Development Experiment (FDE) 1. Workload data were collected via the Bedford Workload Rating Scale and a cockpit controls and displays usability questionnaire. The data were analyzed to determine if the pilot flying the aircraft (pilot on controls) and the pilot operating the mission equipment package (MEP) experienced tolerable and comparable workload levels when performing 35 crew member tasks (see Appendix A). The data were also analyzed to determine whether workload levels contribute to a need to "battle roster[1]" Comanche pilots.

Results indicate that

- Workload was tolerable for the pilots when they performed 33 of the 35 crew member tasks.

- Workload was moderately higher for pilots when they operated the MEP.

- There is no compelling need to prescribe battle rostering for Comanche pilots because (a) workload levels were tolerable when they performed all but one crew member task, and (b) differences in workload levels between the pilot flying the aircraft and the pilot operating the MEP were moderate.

[1]Battle rostering is defined as "the designation of two or more individuals to routinely perform as a crew" (Headquarters, Department of the Army, 1995).

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ASSESSMENT OF CREW WORKLOAD FOR THE RAH-66 COMANCHE FORCE DEVELOPMENT EXPERIMENT 1

1. Introduction

1.1 Purpose and Overview

The RAH-66 Comanche Force Development Experiment (FDE) 1 was conducted from June 6 to 29 2000 with two Comanche portable cockpit (CPC) devices at the Air Maneuver Battle Laboratory, Fort Rucker, Alabama. It was the first of six Force Development Test and Experimentation (FDTE) events that are scheduled to occur from Fiscal Year (FY) 2000 through FY 2006. The purpose of FDE 1 was to assess whether (a) the Comanche pilot and crew procedures are viable for reconnaissance, security, and attack missions in a variety of tactical scenarios; (b) workload levels are evenly and appropriately distributed among crew members; and (c) crew workload levels contribute to a need to "battle roster[2]" Comanche pilots.

The Training and Doctrine Command (TRADOC) System Manager – Comanche (TSM-C) was the sponsor for FDE 1. The TSM-C requested the Human Research and Engineering Directorate of the U.S. Army Research Laboratory (ARL) to assess crew workload during FDE 1. ARL collected crew workload data via the Bedford Workload Rating Scale (see Appendix B) and a cockpit controls and displays usability questionnaire (Appendix C). The data were analyzed to determine if the pilot flying the aircraft (pilot on controls) and the pilot operating the mission equipment package (MEP) experienced tolerable and comparable workload levels when they performed 35 crew member tasks (see Appendix A). Additionally, ARL assessed whether workload levels contribute to a need to battle roster Comanche pilots.

1.2 Assessment of Crew Workload

A common definition of pilot workload is "the integrated mental and physical effort required to satisfy the perceived demands of a specified flight task" (Roscoe, 1985). It is important to assess pilot workload because mission accomplishment is related to the mental and physical ability of the crew to effectively perform their flight and mission tasks. If one or both pilots experience high workload while performing flight and mission tasks, the tasks may be performed ineffectively or may be abandoned. In order to assess whether cockpit workload is evenly and appropriately distributed in the Comanche, the level of workload for each pilot must be evaluated.

[2]Battle rostering is defined as "the designation of two or more individuals to routinely perform as a crew" (Headquarters, Department of the Army, 1995).

1.2.1 Bedford Workload Rating Scale

The Bedford Workload Rating Scale has been used extensively by the military, civil, and commercial aviation communities for pilot workload estimation (Roscoe & Ellis, 1990). It requires pilots to rate the level of workload associated with a task, based on the amount of spare capacity they feel they have to perform additional tasks. Spare workload capacity is an important commodity for pilots because they are often required to perform several tasks concurrently. For example, pilots often perform navigational tasks, monitor radios, and assist the pilot on controls with flight tasks (e.g., maintain air space surveillance) within the same time interval. Mission performance is reduced if pilots are task saturated and have little or no spare capacity to perform other tasks. Design of the Comanche pilot-vehicle interface should help ensure that pilots can maintain adequate spare workload capacity for flight and mission tasks.

1.2.2 Battle Rostering

Battle rostering is believed to improve aircrew workload management by enhancing crew coordination. This is because of increased familiarization and confidence between pilots who routinely train together. If workload levels for Comanche pilots are consistently high or are disproportionately distributed, battle rostering may help them manage their workload more effectively. However, a study by the Army Research Institute (Grubb, Simon, Leedom, & Zeller, 1995) has questioned the benefits of battle rostering. The study identified potential drawbacks, including crew overconfidence, increased use of informal and non-standard procedures, and increased reliance on implicit coordination rather than on explicit coordination behavior between pilots.

1.3 FDE 1 Experimental Procedure

Pilots received 4 weeks of intensive training before the FDE. The training consisted of classroom instruction and "hands-on" flight experience in the CPCs. The pilots flew the same missions (e.g., route reconnaissance) during training that they later flew during the FDE. The mission scenario was based on battlefield environments simulating those depicted in the Comanche operational mode summary and mission profile. The scenario was conducted in four phases (see Table 1). Each successive phase increased in difficulty in order to challenge crew workload. The pilots performed specific planning and in-flight tasks (see Appendix A) during each mission. Each task had prescribed conditions and standards that both crew members had to perform to help ensure mission accomplishment.

Pilots were systematically rotated throughout the missions so that every pilot flew equally often with each of the other pilots. For all missions, the pilot flying the aircraft was assigned to the front seat, and the pilot operating the MEP was assigned to the back seat. Pilots alternated between the front seat and back seat

positions during each phase. A total of 30 missions was conducted during the FDE.

Table 1. Phases of Force Development Experiment 1

Phase	Mission description	Mission objectives
1	Conduct route reconnaissance Conduct point reconnaissance (bridges) Fly to holding area	Navigation, basic mission equipment manipulation, and aircraft control. Arrive at holding area undetected.
2	Conduct route reconnaissance Conduct area reconnaissance Provide security (screen) Engage enemy with artillery	Navigation, advanced mission equipment manipulation, digital communications, call for fire
3	Conduct security operations (screen) Conduct deep reconnaissance Attack theater ballistic missiles React to mission change React to changes in weather	All the above, react to mission changes, and execute procedures for inadvertent entry into instrument meteorological conditions
4[a]	Conduct zone reconnaissance React to mission change React to changes in weather	All the above

[a]NOTE: Crews were battle rostered

1.4 System Description

1.4.1 Comanche Portable Cockpit (CPC)

The CPC (see Figure 1) consists of two (non-motion) cockpits arranged in a tandem configuration and mounted in a transport trailer. The front and rear cockpits are identical, allowing each pilot to perform all crew member tasks. The CPC contains the hardware, MEP, and software that simulate the controls, flight characteristics, and functionality of the Comanche aircraft. The primary cockpit controls and displays are the system management display (SMD), tactical situation display (TSD), cockpit interactive keyboard (CIK), side arm controller (SAC), collective, and the Kaiser ProView 50™ head-mounted display (HMD).

Two CPCs were used during FDE 1. They were programmed with the latest version of flight and mission software in January 2000. The major differences between the CPCs that were used for the FDE and the Comanche aircraft are

- The Kaiser ProView 50™ HMD was used in lieu of the Helmet Integrated Display and Sighting Subsystem (HIDSS). The HIDSS is being developed and will be the production HMD used by Comanche pilots.

- The cockpit geometry of the CPCs was similar but not identical to that of the Comanche aircraft.

- CPCs were not equipped with a motion system.

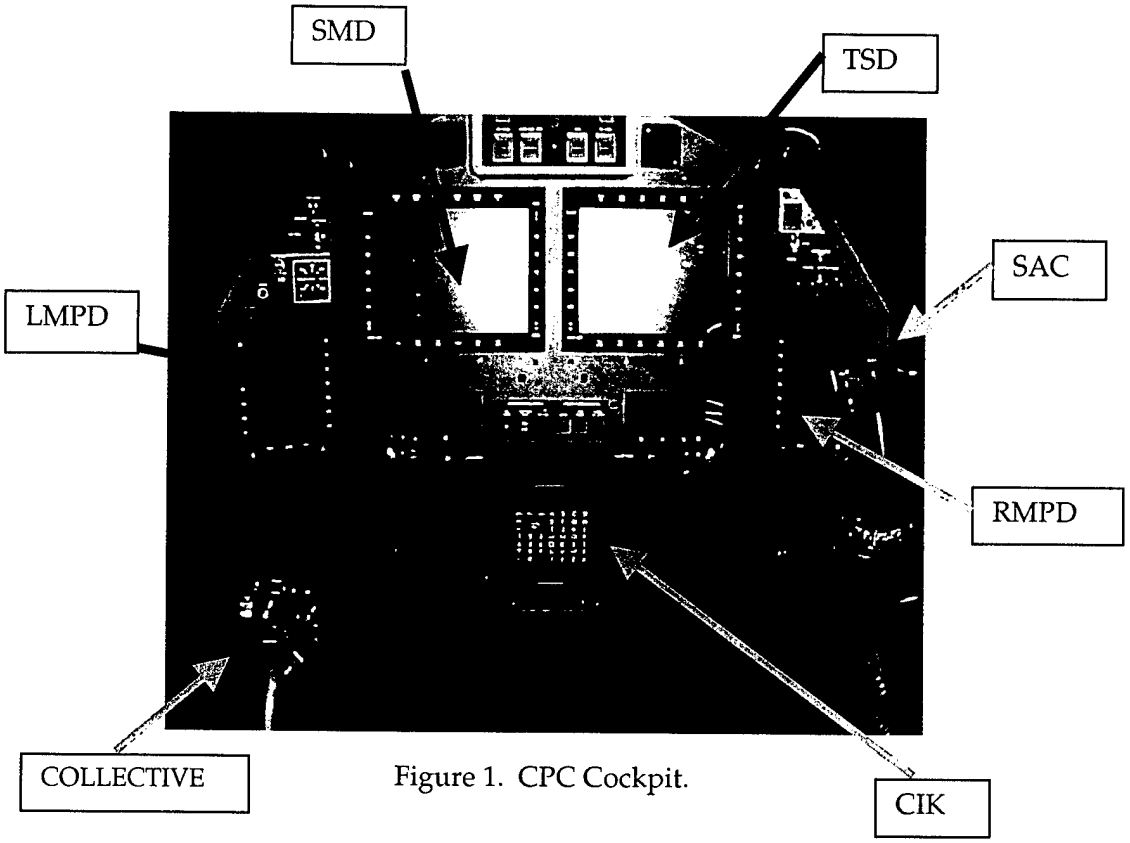

Figure 1. CPC Cockpit.

1.4.2 System Management Display (SMD) and Tactical Situation Display (TSD)

The SMD is a multi-function color display. In one mode, it provides sensor imagery from the target acquisition system (TAS). In other modes, it provides aircraft subsystem control and status information. The TSD is also a multi-function display. It provides a color map and navigational information, including the location of threat and friendly forces. The SMD and TSD each have a bezel incorporating 12 dedicated switches (called mode select keys) in two horizontal rows above and below each of the displays. The six mode select keys on the upper bezel of the SMD are used to select communication functions, while the six mode select keys on the lower bezel allow selection of the main menu of the SMD or aircraft and mission subsystems. The six mode select keys on the upper row of the TSD bezel are used to select HMD functions. The six mode

select keys on the lower TSD bezel allow manipulation of map modes and display characteristics. Switches in the corners of the bezels are used to adjust screen brightness, symbol brightness, and contrast. There are 10 switches in two vertical rows on the right and left of the SMD and TSD. The function and use of these keys vary, depending on the system or subsystem being viewed.

1.4.3 Left and Right Multipurpose Displays (MPDs)

The left MPD (LMPD) is located outboard of the SMD, and the right MPD (RMPD) is located outboard of the TSD. The lower segment of the LMPD contains line address keys, and the upper segment presents the status of selections made from the tactical interactive annunciator panel. The lower segment of the RMPD provides selective monitoring of vehicle subsystems and displays the current settings (frequency, channel preset, transmitter, and ciphony) of the communication radios. The upper segment of the RMPD screen provides information about the operational status and modes of the weapon system and mission equipment.

1.4.4 Collective and Sidearm Controller (SAC)

The collective is located to the left of the crew member's seat, and the SAC is located on the right armrest. The SAC allows pilots to control the pitch, roll, and yaw of the aircraft. It also allows 10% authority vertical input. The collective permits full authority vertical input. Both the collective and SAC grips contain switches that allow hands-on control of critical flight and mission functions. The right armrest also contains switches that control mission functions. The collective, SAC, and right armrest switches are listed in Appendix D.

1.4.5 Cockpit Interactive Keyboard (CIK)

The CIK enables crew members to enter data into the computer system. The data include radio frequencies, coordinates, targets, and text messages.

1.4.6 Helmet-Mounted Display (HMD)

The Kaiser ProView 50™ (see Figure 2) was the HMD used by pilots during FDE 1. It had two liquid crystal displays with 28° (V) by 49° (H) field of view (FOV) (25% binocular overlap), 1024 by 768 resolution, inter-pupillary distance adjustment, eye relief adjustment, adjustable headband and strap, an electronic control unit, and a Polhemus™ head-tracking sensor. The weight of the HMD was 1.3 pounds. The HMD displayed monochrome symbology overlaid on the synthetic visual scene. When used in the night vision pilotage system (NVPS) mode, the HMD displayed the forward-looking infrared (FLIR) scene overlaid by the monochrome symbology. The HMD also displayed an image intensification (I^2) scene overlaid by the monochrome symbology. Pilots selected which scene (FLIR or I^2) was displayed on the HMD. A headset was placed over the HMD to provide the pilots with the capability for radio and inter-cockpit communication.

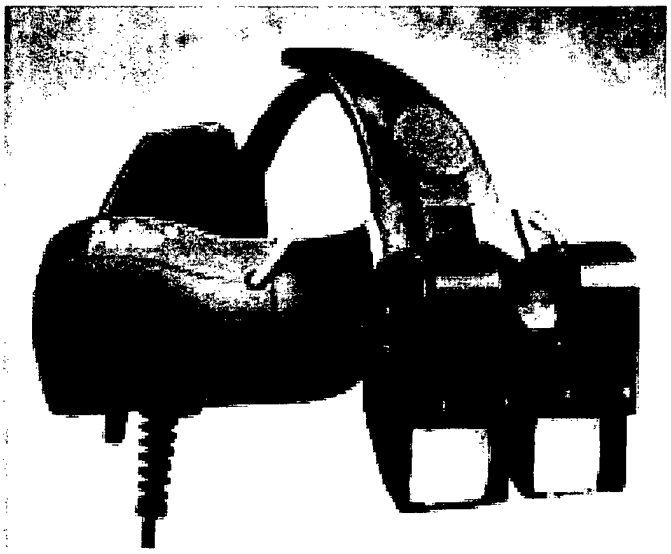

Figure 2. Kaiser ProView 50™.

2. Method

2.1 Participants

Participants were six male Army pilots from the following units: 8-101st Aviation Regiment, Fort Campbell, Kentucky, 1-82nd Aviation Regiment, Fort Bragg, North Carolina, 2-17th Cavalry Squadron, Fort Campbell (two pilots), 3-229th Aviation Regiment, Fort Bragg, and 1-3rd Aviation Regiment, Fort Stewart, Georgia. Three participants were OH-58D pilots who held the rank of CW2. The other three participants were AH-64A pilots who held the rank of CW3. They represented a group of moderately experienced pilots with total flight hours that ranged from 785 hours to 2,170 hours in Army aircraft. None of the participants had previous experience flying a Comanche simulator or aircraft. The relevant demographic characteristics of the pilots are listed in Table 2.

Table 2. Demographic Characteristics of Pilots
(N = 6)

Summary of demographic characteristics	Age (yrs)	Flight hours in primary aircraft	Total flight hours in Army aircraft	Flight hours with night vision devices
Average	34	910	1292	480
Median	34	800	1180	435
Range	26-41	620-1500	785-2170	352-707

2.2 Data Collection

Two questionnaires were developed in order to assess workload for the crew member tasks listed in Appendix A. One of the questionnaires required the pilots to rate their perceived level of workload for each crew member task via the Bedford Workload Rating Scale. The other questionnaire required pilots to rate whether (a) usability features of the cockpit controls and displays impacted their workload levels during the mission, and (b) workload was higher for the pilot flying the aircraft (front seat) or the pilot operating the MEP (back seat). The purpose of this questionnaire was to highlight any usability problems that contributed to excessive workload during the mission and to help determine if workload was evenly distributed between pilots.

The questionnaires were developed in accordance with published guidelines for proper format and content (Babbitt & Nystrom, 1989). A brief pre-test was conducted to refine the questionnaires and to ensure that they could be easily understood and completed by pilots. Before experimentation, the FDE pilots were briefed about the purpose of the workload assessment. They also received instruction about completing both questionnaires.

The pilots provided workload ratings for each applicable crew member task immediately after every mission. They completed the cockpit controls and displays usability questionnaire at the end of each phase. Questionnaire results were clarified with information obtained during post-flight discussions with pilots.

2.3 Data Analysis

Pilot responses to the workload rating questionnaire and cockpit controls and displays usability questionnaire were analyzed with averages and percentages. In addition, the sign test was used to identify any statistically significant differences in workload ratings between the pilot on controls and the pilot operating the MEP. The chi-square goodness-of-fit and binomial tests were used to identify any statistically significant response trends to questionnaire items regarding whether the usability characteristics of the cockpit controls and displays impacted workload. Statistically significant trends indicate that the responses provided by the pilots to the questionnaire items were not random but were attributable to factors such as strong favorable or unfavorable opinions about usability characteristics of the cockpit controls and displays. Because of the small number of pilots who participated in the FDE, probability values were computed via Fisher's Exact Test.

Because the pilots had limited experience with the CPCs before experimentation began, correlation coefficients were computed to identify any significant changes in their responses to the controls and displays usability questionnaire over the course of the FDE. This was done to help determine if increased experience with

the system significantly affected pilot responses to questionnaire items. For example, pilots might rate a component as much easier to use toward the end of the FDE because of increased experience with using it during previous missions. Significant changes in their responses might indicate that (a) pilots would have benefited from additional training, and (b) the additional training would have allowed the pilots to provide more valid responses during the early phases of the FDE.

2.4 Limitations of Workload Assessment

Limitations included the small sample size of pilots (N = 6) who participated in the FDE, their limited experience (2 months) with the CPCs, and the lack of 100% fidelity between the CPCs and the Comanche aircraft. Information and data listed in the Results and Summary sections of this report should be interpreted on the basis of these limitations.

3. Results

3.1 Workload When Pilots Performed Crew Member Tasks

As summarized in Table 3 and Appendix E, pilots reported that workload was tolerable when they performed all front and back seat tasks except "maintaining air space surveillance". Pilots in the back seat could not maintain air space surveillance at night because they had no night vision device (FLIR or night vision goggles) to see outside the cockpit while they conducted a scan with the TAS.

3.2 Spare Workload Capacity When Pilots Performed Crew Member Tasks

Pilots reported that they experienced no reduction in spare workload capacity while they performed 24 (69%) crew member tasks in the front seat and 17 (63%) tasks in the back seat. When flying the aircraft from the front seat, pilots reported that they experienced "insufficient spare workload capacity for *easy* attention to additional tasks" while they performed 11 (31%) crew member tasks. This is understandable for 8 of the 11 tasks because they are inherently workload-intensive events because pilots are (a) attempting to engage or avoid the threat or (b) responding to an emergency or unexpected event. The other three tasks (digital communications, data entry procedures, and data management operations) received this rating primarily because of usability problems with the CIK and the TSD (see Table 4). Pilots reported that entering data on the CIK was time consuming and required excessive steps. Specific items that were reported as being difficult to enter included radio frequencies, targets, and coordinates. The slow processing speed of the CIK was also cited as a usability problem.

Pilots reported that labeling targets on the TSD was time consuming because of the excessive number of steps required to perform the task.

Table 3. Summary of Workload Ratings

Pilot on controls (front seat)	Pilot operating the MEP (back seat)
Workload was tolerable when pilots performed all tasks	Workload was tolerable when pilots performed all tasks except "maintaining air space surveillance"
Pilots experienced no reduction in spare workload capacity when performing 24 of 35 tasks (69%)	Pilots experienced no reduction in spare workload capacity when performing 17 of 27 tasks (63%)
Pilots experienced "insufficient spare workload capacity for *easy* attention to additional flight and mission tasks" when performing · Evasive maneuvers · Firing techniques · Inadvertent IMC procedures · Data management operations · Target engagement with AWS · Target engagement with PTWS · Actions on contact · Firing position operations · Emergency procedures · Data entry procedures · Digital communications	Pilots experienced "insufficient spare workload capacity for *easy* attention to additional flight and mission tasks" when performing · Radio communications · TSD operations · Target engagement with AWS · Identification of major U.S.-allied equipment and major threat equipment · Operation of the NVPS · Inadvertent IMC procedures Pilots experienced "reduced spare workload capacity." Additional tasks could not be given the desired amount of attention when performing: · Data management operations Pilots experienced "little spare workload capacity; their level of effort allowed little attention to additional tasks" when performing · Digital communications · Data entry procedures Pilots could not perform the following task at night because they did not have a night vision device to see outside the cockpit while conducting a scan with the TAS · Maintaining air space surveillance

IMC = instrumented meteorological conditions
AWS = area weapon system
PTWS = point target weapon system

Table 4. Impact of Usability Characteristics of Cockpit Controls and Displays on Workload

CIK	MPDs	SMD	TSD
		Steps to accomplish task	
Pilots reported that using the CIK was significantly time consuming for most missions because steps required to accomplish functions were excessive and not logical or consistent. Pilots reported that the CIK should be modified to decrease workload.	Pilots reported that using the MPDs was not significantly time consuming (for most missions) because of the steps required to complete a function. Pilots reported that some modifications should be made in the MPDs to help decrease workload.	Pilots reported that using the SMD was not significantly time consuming (for most missions) because of the steps required to complete a function. Pilots reported that some modifications should be made in the SMD to help decrease workload.	Pilots reported that using the TSD was significantly time consuming for 50% of missions because steps required to accomplish functions were excessive and not logical or consistent. Pilots reported that modifications should be made in the TSD to decrease workload.
		Menu navigation	
Not applicable	Pilots were able to quickly navigate through the menu screens for 96% of missions.	Pilots were able to quickly navigate through the menu screens for 91% of missions.	Pilots were able to quickly navigate through the menu screens for 71% of missions.
Not applicable	Pilots seldom or never had trouble remembering where they were in the menu system for all missions.	Pilots seldom or never had trouble remembering where they were in the menu system for all missions.	Pilots seldom or never had trouble remembering where they were in the menu system for all missions.
		Symbology	
Not applicable	Not applicable	Pilots reported that they could quickly and easily understand symbology displayed on the SMD during all missions.	Pilots reported that they could quickly and easily understand symbology displayed on the TSD for 65% of missions. Pilots reported that some modifications of the symbology should be made to decrease workload.

When operating the MEP in the back seat, pilots reported that they experienced "insufficient spare workload capacity for *easy* attention to additional tasks" while they performed six (22%) crew member tasks. This is understandable for four of the six tasks because they are inherently workload-intensive events because pilots are (a) attempting to identify, engage, or avoid the threat or (b) responding to an unexpected event (inadvertent IMC). The other two tasks (radio communications and TSD operations) received this rating primarily because of usability problems with the CIK and the TSD. The usability problems are the

same as those identified by the pilots when they flew the aircraft from the front seat (see previous paragraph). Pilots reported that they experienced "reduced spare workload capacity" while they performed data management operations and "little spare workload capacity" while they performed digital communications and data entry procedures. Again, pilots cited usability problems with the CIK and TSD as the primary reasons for assigning these ratings to the tasks. Finally, pilots could not maintain air space surveillance at night because they did not have a night vision device to see outside the cockpit while they conducted a scan with the TAS.

3.3 Comparative Workload Levels Between Front Seat and Back Seat

No statistically significant differences in workload ratings were provided by pilots when they flew the aircraft versus when they operated the MEP. However, when asked to rate whether overall workload was higher for the front or back seat for the missions they performed, pilots reported that workload was somewhat higher (54%) or much higher (22%) for the back seat compared to the front seat. The primary reason given by the pilots was that operating the MEP required the crew member to perform more tasks in the same time interval than the crew member who was flying the aircraft. Also, pilots reported during post-flight discussions that usability problems with the CIK, TSD, and "slew" hook-FOV switches on the collective grip contributed to higher workload for the pilot in the back seat. The pilot operating the MEP uses the CIK, TSD, and FOV-slew switches more often during the mission than does the pilot flying the aircraft.

3.4 Pilot Responses to Controls and Displays Usability Questionnaire

Increased experience with the CPC over the course of the FDE did not affect pilot responses to the controls and displays usability questionnaire items. No significant correlation coefficients were obtained when pilot responses were analyzed. The ratings provided by the pilots were consistent between each phase of the FDE. This indicates that the training they received before the FDE was sufficient for them to identify the usability characteristics of cockpit controls and displays that contributed to increased workload. Discussions with pilots also indicated that they were able to easily identify (early in training) the usability characteristics of the controls and displays that contributed to higher workload.

3.5 HMD Symbology

Pilots reported that it was difficult to quickly and easily understand the heading tape displayed in the HMD when they flew the aircraft or operated the MEP. They unanimously requested that the heading tape be stabilized and not move when the pilot moves his head. The pilots also requested that pitch ladder and bank angle symbols be added to the HMD symbology set.

4. Summary

4.1 Cockpit Workload

Results indicate that (a) workload was tolerable for pilots when they performed all but one crew member task; (b) pilots experienced no reduction in spare workload capacity for 69% of tasks when they flew the aircraft and for 61% of tasks when they operated the MEP; and (c) workload was moderately higher for pilots when they operated the MEP versus when they flew the aircraft. Following is a brief summary of the results:

- Pilots experienced tolerable workload levels for all tasks when they flew the aircraft. They experienced tolerable workload levels for all but one task when they operated the MEP. Workload was not tolerable for the task of "maintaining air space surveillance" at night for the pilot operating the MEP. This was because there was no night vision device for seeing outside the cockpit when the pilots conducted a scan with the TAS.

- Pilots experienced no reduction in spare workload capacity for 69% of tasks when they flew the aircraft and for 61% of tasks when they operated the MEP. For tasks in which a reduction in spare workload capacity was experienced, the primary reasons were

  - The tasks were inherently workload intensive because pilots were identifying, engaging, or avoiding a threat or responding to an emergency or unexpected event.

  - Usability problems with the CIK, TSD, and FOV-slew switches on the collective.

- Workload levels were higher for pilots when they operated the MEP. The primary reasons were

  - Operating the MEP required pilots to perform more tasks during the mission than when they flew the aircraft.

  - Usability problems with the CIK, TSD, and FOV-slew switches on the collective increased workload for pilots when they operated the MEP. The pilot operating the MEP uses the CIK, TSD, and FOV-slew switches more often during the mission than does the pilot flying the aircraft.

- Pilots unanimously requested that the heading tape displayed in the HMD be stabilized and not move when the pilot moves his head. They also requested that pitch ladder and bank angle symbols be added to the HMD symbology set.

4.2 Battle Rostering of Comanche Pilots

Results indicate that there is no compelling need to prescribe battle rostering because of high or disproportionately distributed workload between Comanche pilots. This is because (as summarized on the previous page)

- Workload was tolerable for all but one of the crew member tasks performed by pilots.

- Pilots experienced no reduction in spare workload capacity for 69% of tasks when they flew the aircraft and for 61% of tasks when they operated the MEP.

- Only moderate differences in workload levels were reported between pilots when they flew the aircraft versus when they operated the MEP.

5. Recommendations

Data obtained during FDE 1 provide useful insights about workload levels that Comanche pilots may experience when performing crew member tasks. The data also identified usability limitations with the CIK, TSD, slew hook and FOV switches on the collective, and symbology on the HMD (see Appendix C). These usability limitations should be addressed and resolved as soon as possible. Additionally, the pilot operating the MEP should be provided with a night vision device to see outside the cockpit at night when he conducts a scan with the TAS.

The scope of FDE 1 did not allow a comprehensive evaluation of workload for Comanche pilots. To fully assess the design of the Comanche, future FDTE events should include comprehensive evaluations of pilot workload. Other (related) performance measures such as crew coordination, situational awareness, and decision making should be evaluated to help assess workload and fully develop the pilot-vehicle interface.

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APPENDIX A

FDE 1 CREW MEMBER TASKS

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FDE 1 Crew Member Tasks		
Task 1035 – Perform Before Flight Checks	Task 1162 - Perform Actions On Contact	Task 1442 - Perform HIDSS Operations
Task 1042 - Maintain Airspace Surveillance	Task 1168 – Select Landing Zone/Holding Area	Task 1448 - Perform EOTADS Sensor Operations
Task 1100 - Perform Radio Communications	Task 1173 - Perform VMC Approach and Roll-on Landing	Task 1449 - Perform Digital Communications
Task 1107 - Perform Hovering Flight	Task 1230 - Perform Inadvertent IMC Procedures	Task 1454 – Perform Data Entry Procedures
Task 1109 - Perform VMC Takeoff	Task 1300 - Perform Emergency Procedures	Task 1455 - Perform Data Management Operations
Task 1117 - Perform VMC Flight Maneuvers	Task 1410 - Perform TSD Operations	Task 1458 – Engage Target With PTWS
Task 1127 - Perform Electronically Aided Navigation	Task 1414 – Perform Target Handover	Task 1464 - Engage Target With The AWS Turreted Gun
Task 1136 - Perform Terrain Flight Navigation	Task 1422 – Perform Firing Techniques	Task 1500 - Perform Aerial Observation
Task 1146 - Perform Terrain Flight	Task 1426 - Perform Firing Position Operations	Task 1805 - Identify Major US-Allied Equipment and Threat Equipment
Task 1148 - Perform Terrain Flight Deceleration	Task 1427 – Select A Combat Position	Task 1823 - Operate Aircraft Survivability Equipment
Task 1151 - Perform Masking And Unmasking	Task 1428 - Select Appropriate Weapon System	Task 1837 - Operate Night Vision Pilotage System
Task 1153 - Perform Evasive Maneuvers	Task 1440 - Perform HIDSS Boresight	

VMC = visual meteorological conditions
EOTADS = electro-optical target acquisition designation system

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APPENDIX B

BEDFORD WORKLOAD RATING SCALE

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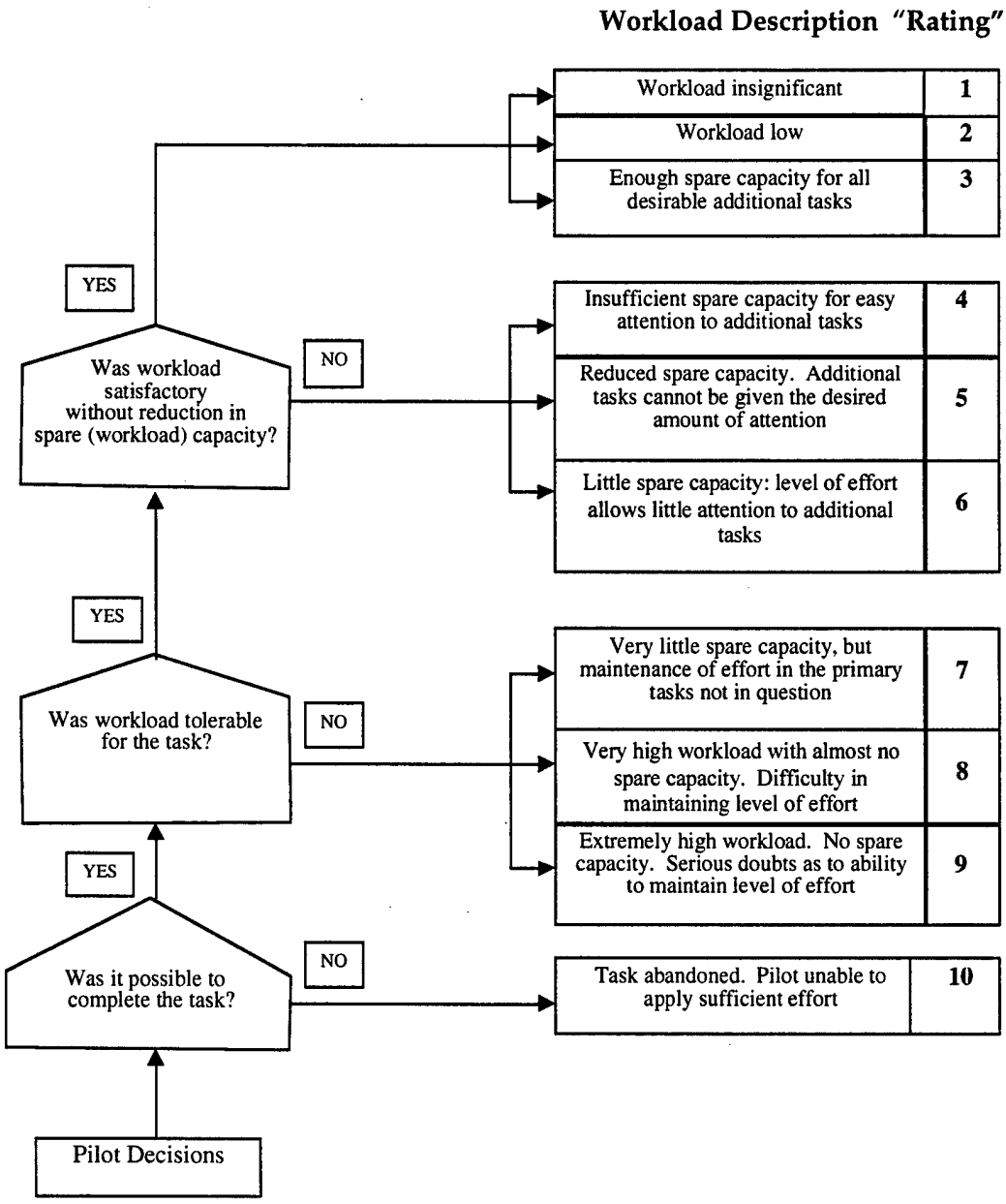
Workload Description "Rating"
Workload insignificant
1
Workload low
2
Enough spare capacity for all desirable additional tasks
3
YES
Was workload satisfactory without reduction in spare (workload) capacity?
NO
Insufficient spare capacity for easy attention to additional tasks
4
Reduced spare capacity. Additional tasks cannot be given the desired amount of attention
5
Little spare capacity: level of effort allows little attention to additional tasks
6
YES
Was workload tolerable for the task?
NO
Very little spare capacity, but maintenance of effort in the primary tasks not in question
7
Very high workload with almost no spare capacity. Difficulty in maintaining level of effort
8
Extremely high workload. No spare capacity. Serious doubts as to ability to maintain level of effort
9
YES
Was it possible to complete the task?
NO
Task abandoned. Pilot unable to apply sufficient effort
10
Pilot Decisions

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APPENDIX C

SUMMARY OF PILOT RESPONSES ABOUT THE USABILITY CHARACTERISTICS OF THE CREW STATION CONTROLS AND DISPLAYS

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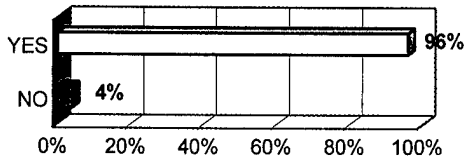
SUMMARY OF PILOT RESPONSES REGARDING USABILITY CHARACTERISTICS OF CREW STATION CONTROLS AND DISPLAYS

Any CIK Functions That Were Significantly Time Consuming to Accomplish Due to Excessive Number of Steps?**

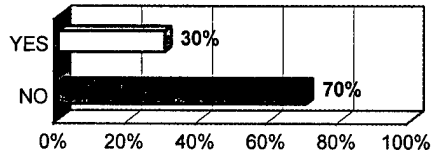


Pilot Comments:

Problems when using the CIK:

- CIK is too cumbersome (4 comments).
- CIK is too cumbersome when data are entered.
- The CIK is cumbersome and slow.
- Cumbersome- would like voice interaction
- Excessive number of steps for CIK use.
- All (CIK, MPDs, SMD, and TSD) required an excessive number of steps.
- Too many steps to enter anything in the CIK.
- Location and interface difficult.
- Need quicker method of entering manual frequencies and waypoints for direct to.
- CIK should be enabled for direct waypoint entry by 8-digit grid.
- Manual entry at grid for FLT plan, direct waypoints (should be more interactive.).
- Trying to make sentences takes too long.
- Keyboard needs to be able to be interactive with more functions, such as entering a direct waypoint, or a manual radio frequency.
- Difficult to interact with. Would like a manual selection to enter commo, freqs, or grid locations. Very slow and not user friendly when interacting with commo and NAV package.
- Changing radio frequencies, it would be nice to have a control head. It would be a lot easier to change a manual frequency.
- Key positioning requires "hunt and peck."
- It is too slow.

Any MPD Functions That Were Significantly Time Consuming to Accomplish Due to Excessive Number of Steps?

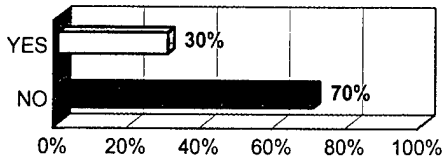


Pilot Comments:

- RMPD- Fuel quantity indicator is very hard to focus on. When checking fuel, I find myself "inside the cockpit" far too long.
- Fuel display.
- RMPD is cluttered and is very hard to disseminate info.
- When selecting a radio, I spent too much time looking down at RFD. Difficult to see the display and forced to look at it when selecting radio.
- Multi-level menus are sometimes too deep.
- When selecting a hard bezel should always go to top TMI. Recognition of what level you are in requires time.
- Visual indication of 20 mm deployed (picture).

**Significant at α .01

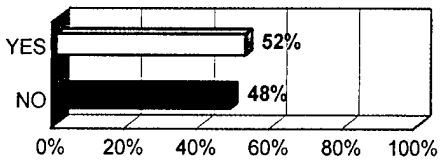
Any SMD Functions That Were Significantly Time Consuming to Accomplish Due to Excessive Number of Steps?



Pilot Comments:

- Any hard bezel selection should kick you out of the slaved function. (4 comments)
- Windows and digital communications
- Communication pages
- Windows.
- TAS manual/use.
- TAS sensitive to aircraft in main slew mode.

Any TSD Functions That Were Significantly Time Consuming to Accomplish Due to Excessive Number of Steps?



Pilot Comments:

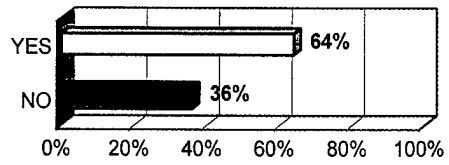
Problems with labeling of targets:

- TGT labeling.
- Labeling targets is time consuming. Suggest a selectable bar on TSD.
- Labeling function too time consuming and cumbersome/windows.
- Labeling takes too long.
- Labels.
- Label function excessive.
- Labeling targets is very time consuming.
- Labeling of TGTS should be a selection on LMPD. Current method is time consuming and awkward.

Other comments:

- Icons should be scaled to map. (2 comments)
- Threat ID classification. Right slew hook and design should be moved to a time menu item on LMPD.
- MAP is cluttered.
- Hook function and picking between two targets that are very close together.

Any CIK Functions That Were Significantly Time Consuming to Accomplish Due to Steps That Were Not Logical or Consistent?

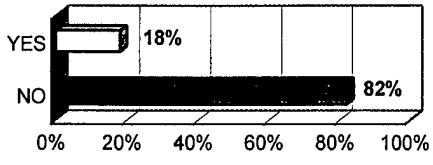


Pilot Comments:

Problems when using the CIK:

- Too cumbersome. (2 comments)
- All CIK functions. (2 comments)
- The keyboard needs to be designed with a "PC style layout. (2 comments)
- Too many steps.
- Too many steps for use.
- This CIK takes too long to utilize.
- Too slow.
- The CIK takes too long to input data.
- Manual entry for both frequencies and waypoints.
- Should always be able to activate keyboard for grids-spot reports

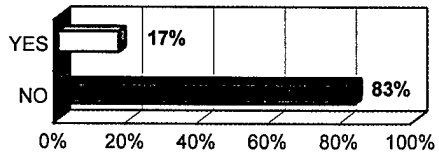
Any MPD Functions That Were Significantly Time Consuming to Accomplish Due to Steps That Were Not Logical or Consistent??**



Pilot Comments:

- The direct to function in NAV-CUR is not in logical sequence when using in conjunction with locate.
- Multiple level menus.
- There were too many items that are split between the TIMI menu structure and hard bezels on the MPD's.
- When selecting hard bezel, should always go to top TMI.

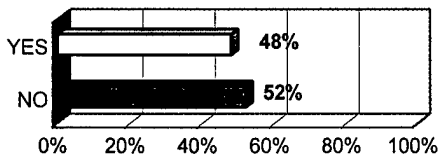
Any SMD Functions That Were Significantly Time Consuming to Accomplish Due to Steps That Were Not Logical or Consistent??**



Pilot Comments:

- Windows. (2 comments)
- Using any function on SMD, you lose sight of target in TAS.
- Communication systems.

Any TSD Functions That Were Significantly Time Consuming to Accomplish Due to Steps That Were Not Logical or Consistent?

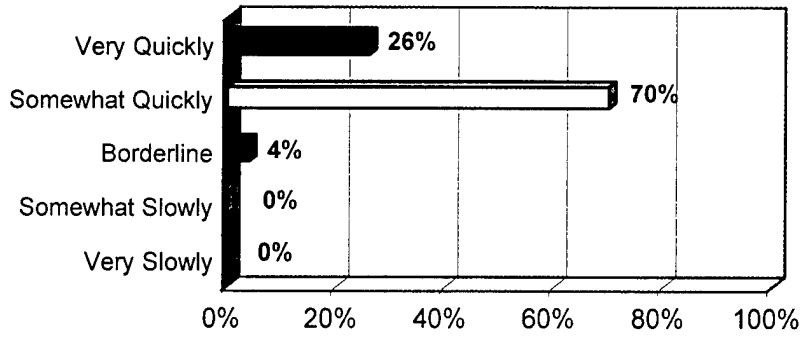


Pilot Comments:

- Labeling function is slow. (3 comments)
- Labels. (2 comments)
- Labeling takes too long.
- Labeling targets.
- Direct-to and show on map.

**Significant at α .01

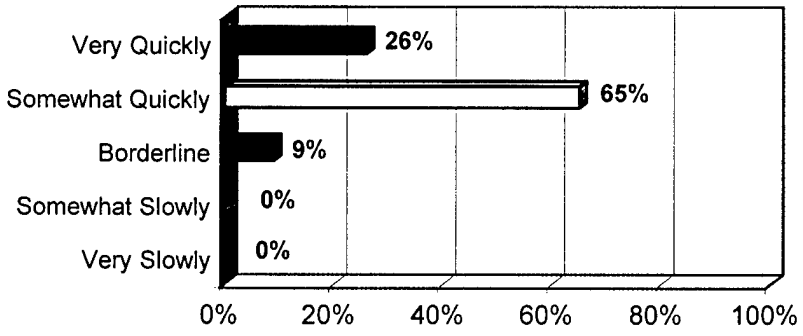
How Quickly Were You Able to Navigate Through the Menu Screens on the MPDs?**



Pilot Comments:

- No comments provided by pilots.

How Quickly Were You Able to Navigate Through the Menu Screens on the SMD?**

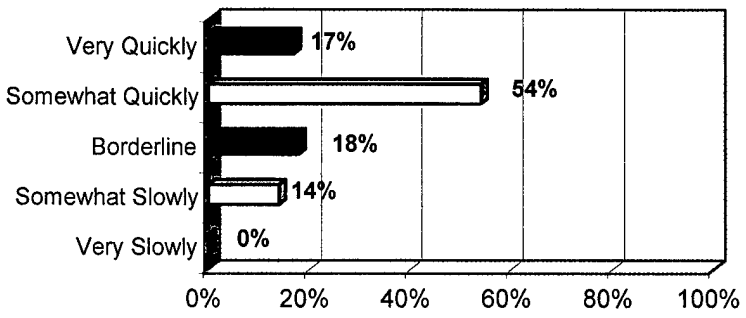


Pilot Comments:

- I would like to have more menu selections displayed on either the TIMI or SMD and not both. There is no logical reason why a selection is on either the TIMI or SMD.

**Significant at α .01

How Quickly Were You Able to Navigate Through the Menu Screens on the TSD?**



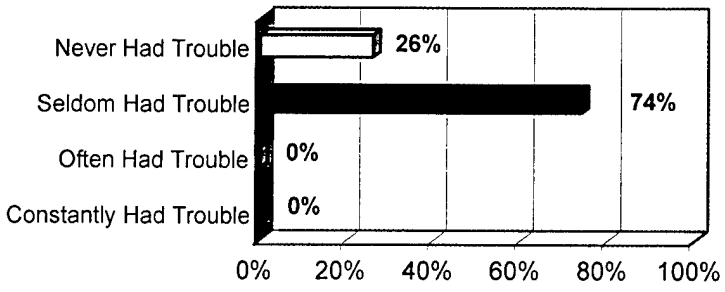
Pilot Comments:

Problems with labeling of targets:

- Target labeling.
- Labeling slow.
- The labeling function and TSD windows function are very slow. As well as plotting a direct waypoint.
- Labeling and windows.
- TGT labeling.
- Only in labeling menus.
- The menu structure for TSD labeling is very poor.
- Threat ID classification with right slew hook- too much time. Should be choices on SMD and TSD.

**Significant at α .01

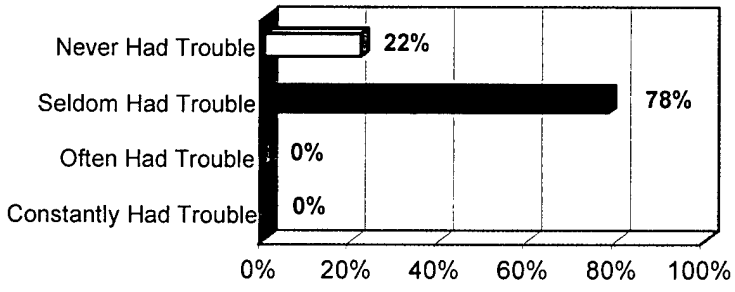
How Often Did You Have Trouble Remembering Where You Were in the MPD Menu System?**



Pilot Comments:

- No comments provided by pilots.

How Often Did You Have Trouble Remembering Where You Were in the SMD Menu System?**

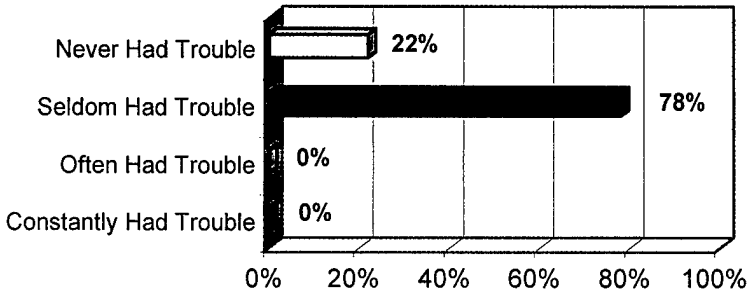


Pilot Comments:

- No comments provided by pilots.

**Significant at α .01

How Often Did You Have Trouble Remembering Where You Were in the TSD Menu System?**

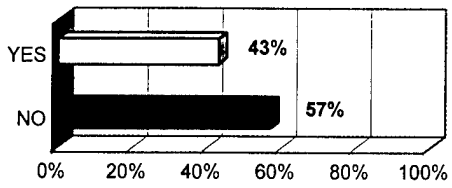


Pilot Comments:

- TSD windows can get confusing sometimes. I like the purpose of windows, however I think it could be easier to use.

**Significant at α .01

Were Any Switches on the Collective Grip Time Consuming to Use ?



Pilot Comments:

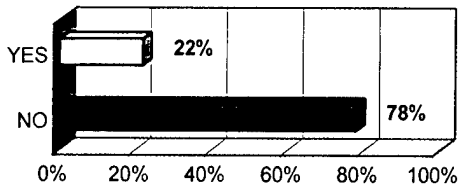
Problems with slew hook and FOV switches:

- Slew hook functions.
- Both slew hooks and FOV zoom select switch.
- Slew Hook/ FOV switches.
- The FOV selection switch on the collective is not in logical order. The optics are displayed as follows: MWN. The order they should follow is WMN.
- Field of view needs logical order.
- Front/Back: the FOV selection switch does not select between narrow, medium and wide in a logical order.

Other comments:

- Map Scale- include 18 and 32 k scales.
- Front/Back: the map scale switch should also have option for 18K map scale.
- The "no target" and "details" are difficult to find without visual verification. Both seats.
- Radio selection - Would like five position switch.

Were Any Switches on the Sidearm Controller Time Consuming to Use* ?

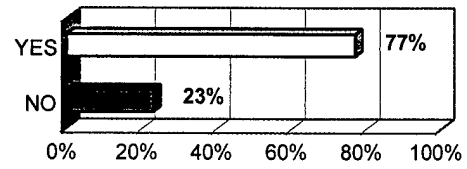


Pilot Comments:

- Right arm controller very difficult to use.
- Arm and cyclic inputs difficult.
- Need detachable controller (Nintendo®).
- AFCS difficult to reach/slant control force.
- Finding the "take flight control" is difficult.
- The SAC needs to be more user friendly. That is, easier to hold on to and use the switch at the same time.

*Significant at α .05

Was There Any Symbology on the HMD That Was Difficult to Quickly and Easily Understand*?



Pilot Comments:

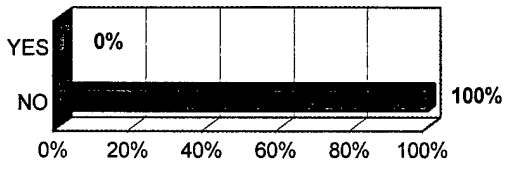
Problems with heading tape:

- Heading tape should be screen stabilized (6 comments)
- Heading tape should be fixed (not moving). (2 comments)
- Heading tape should be HMD stabilized. (2 comments)
- Heading tape needs to be fixed to the aircraft.
- I still do not like the moving heading tape. It should be fixed.
- Heading tape should be stable.
- The heading tape needs to be stable. It can cause vertigo.

Other comments:

- Need to add pitch ladder (4 comments)
- Need to add bank angle. (3 comments)
- No TAS LOS bearing indicator.
- False horizon nearly impossible to use for any turn rate or A/C attitude determination. Excessive movement of symbology confusing almost imparting the desire to input an incorrect change in A/C attitude.
- WCA not easily identified without audio.
- Cannot see outside when operating TAS.
- Symbology for NVS flight predictor worse than all others as previously stated.
- 20 mm ownership not displayed.
- Hellfire ownership not displayed.

Was There Any Symbology on the SMD That Was Difficult to Quickly and Easily Understand?**

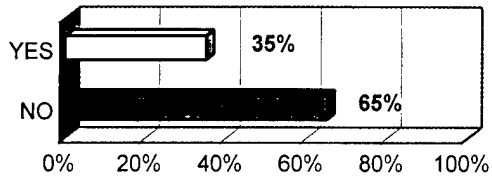


Pilot Comments:

- No comments provided by pilots.

*Significant at α .05
**Significant at α .01

Was There Any Symbology on the TSD That Was Difficult to Quickly and Easily Understand*?



Pilot Comments:

- 18th K view targets close to one another; difficult to break out and overlaid symbology selects when hooked. That is, hook difficult to pick between two different items that occupy the same space on the MAP.
- Wires and roads are red.
- Digital map symbols are different than the chart symbols that every aviator is familiar with. Icon should also be scaled proportionally to map scale.
- ADA searching symbol difficult to see. Sensor shading on map. Line of sight with terrain shading for line of sight inter-visibility.
- Visual alert of ADA (ASE radar or laser warning) on map. - I would like to have the symbols red instead of black. I would like to have it flashing to catch my attention if it is a new system searching.
- The non-labeled vehicle icons are hard to tell the difference between a wheeled and tracked vehicle icon. They should look more like a truck and a tank.
- WCA not noticed without audio alarm (move to bottom).
- Target icons in proximity to graphics and each other; hard to separate.

APPENDIX D

COLLECTIVE, SIDE ARM CONTROLLER, AND RIGHT ARMREST SWITCHES

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COLLECTIVE, SIDE ARM CONTROLLER, AND RIGHT ARMREST SWITCHES

Collective switches	Side arm controller switches
Searchlight	Automatic flight control system
Trim	
Guarded jettison release	Coupler release
Sensor FOV/sensor control	NVPS I^2/IR and polarity select
Cursor control for TAS (left slew hook)	Station deselect
No target designation switch	Trigger guard
Target select and sensor locking	Weapon release
Location designation switch	Weapon select
Cursor control for TSD (right slew hook)	Yaw trim release
Map selection/scale selection	Integrated flight-fire control (IFFC)
Slew to own helmet sensor control	
Collective trim release	
Radio/preset select switch	
Warning, caution, advisory acknowledge	
Laser activation switch	
Hover return	

Right armrest switches
Right slew hook
Left slew hook
Laser
Details
Find

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APPENDIX E

SUMMARY OF PILOT RESPONSES TO BEDFORD WORKLOAD RATING SCALE

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SUMMARY OF PILOT RESPONSES TO BEDFORD WORKLOAD RATING SCALE

Crew Member Tasks	Front Seat Workload Rating	Back Seat Workload Rating	Crew Member Tasks	Front Seat Workload Rating	Back Seat Workload Rating
Perform Before Flight Checks	1.82	2.07	Perform Terrain Flight Deceleration	3.23	NA
Maintain Airspace Surveillance	2.56	a	Perform Masking And Unmasking	2.96	NA
Perform Radio Communi-cations	3.30	3.60	Perform Evasive Maneuvers	4.28	NA
Perform Hovering Flight	2.13	NA	Perform Actions on Contact	4.00	3.37
Perform VMC Takeoff	2.42	NA	Select Landing Zone/Holding Area	3.20	3.09
Perform VMC Flight Maneuvers	2.58	NA	Perform VMC Approach	2.73	NA
Perform Electronically Aided Navigation	2.93	2.72	Perform Inadvertent IMC Procedures	3.77[b]	3.62[b]
Perform Terrain Flight Navigation	2.96	2.66	Perform Emergency Procedures	3.80[b]	3.20[b]
Perform Terrain Flight	3.23	NA	Perform TSD Operations	3.21	3.89

[a]Task could not be completed at night because there was no night vision device for use while pilots conducted a scan with the TAS.
[b]Based on ratings from fewer than 10 missions.

Crew Member Tasks	Front Seat Workload Rating	Back Seat Workload Rating	Crew Member Tasks	Front Seat Workload Rating	Back Seat Workload Rating
Perform Target Handover	2.76	3.00	Perform Digital Communi-cations	4.53	6.10
Perform Firing Techniques	3.76	3.31	Perform Data Entry Procedures	4.35	6.00
Perform Firing Position Operations	3.52	3.10	Perform Data Management Operations	3.60	4.59
Select A Combat Position	3.09	2.95	Engage Target With PTWS	3.80	3.00
Select Appropriate Weapon System	2.42	2.75	Engage Target With The AWS Turreted Gun	4.40[a]	4.16[a]
Perform HIDSS Boresight	2.20	2.48	Perform Aerial Observation	2.96	3.30
Perform HIDSS Operations	2.60	3.04	Identify Major U.S./Allied Equipment and Major Threat Equipment	3.29	3.58
Perform EOTADS Sensor Operations	3.00[a]	3.39	Operate Aircraft Survivability Equipment	2.70	2.44[a]

[a]Based on ratings from fewer than 10 missions.

Crew Member Tasks	Front Seat Workload Rating	Back Seat Workload Rating
Operate Night Vision Pilotage System	2.60	3.88[a]

[a]Based on ratings from fewer than 10 missions.

Comments regarding lack of external vision in the back seat:

- Task 1042: (Airspace Surveillance) Back seat has no vision.
- Task 1042: Not able to perform airspace surveillance due to lack of night vision.
- Task 1042: B/S has no outside vision
- Task 1042: Can't see in the back when not flying.
- Task 1042 cannot be performed due to lack of night vision in rear seat during scans.
- Task 1500 (Aerial Observation): Can't quickly scan around aircraft (no vision). Would like NVG or equivalent.
- Tasks 1153 (Evasive Maneuvers), 1162 (Actions On Contact), 1442 (HIDSS Operations) and 1448 (EOTADS Sensor Operations): During maneuvering CP unable to acquire TGT with TAS Auto or manual. Since CP is HMD blind, the CP was unable to acquire target with HIDSS.
- Task 1837 (Operate Night Vision Pilotage System): Not available, so abandoned flight to FS.
- I have no visual in the back

Comments regarding the CIK:

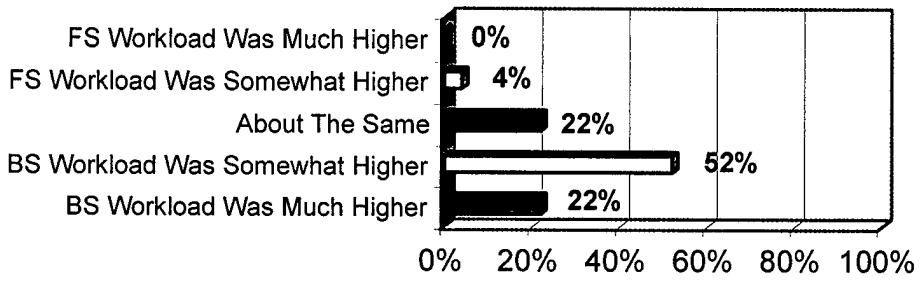
- Tasks 1449 (Digital Communications and 1454 (Data Entry Procedures): CIK very cumbersome. (2 comments)
- Digital communications are totally absorbing.
- Task 1100 (Radio Communications): CIK very cumbersome
- The CIK is not user friendly and too slow.
- Using the CIK and using I2 is cumbersome. The whole digital processing needs work.
- The CIK needs to be more user-friendly.

Comments regarding other cockpit interface problems:

- Task 1410 (TSD Operations) Controls are difficult to operate which causes workload to be higher.
- TAS view last, multi-step must complete before continuing with other functions.
- Data procedures require excessive number of steps and are difficult to work with current controls.
- HIDSS symbology: Reference to aircraft attitude and turn angle difficult to determine from looking off nose or slides. Determining rate of turn impossible. Just guessing at it from movement of heading tape. Predictor a waste of space, pilot must fly terrain.
- 1449 (Digital Communications) and 1455 (Data Management Operations): Vocal reports used to augment diagram because of poor interface.
- Task 1455 (Data Management Operations): Labeling targets cumbersome.

- Tasks 1410 (TSD Operations, 1442 (HIDSS Operations), 1449 (Digital Communications), 1454 (Data Entry Procedures), 1455 (Data Management Operations) and 1837 (Operate Night Vision Pilotage System): System interface is cumbersome requiring excessive time.
- Task 1162 (Actions On Contact) - Only focus was flying the A/C.
- Tasks 1422 (Firing Techniques) and 1426 (Firing Position Operations): Wouldn't allow an engagement.
- When the MPED would direct WP the NAI, I could not see the line on my TSD.
- Had to wait a long time for target ID.
- TSD/TAS labeling due to ATS not Id'ing targets 5K and under. INT not functioning properly.
- Encountered ADA and had to quickly mask without crashing.
- Task 1442 (HIDSS Operations): Not used for other than missile constraints.
- Unable to load and select presets.

Rate Whether Overall Workload was Higher for the Front Seat or Back Seat**?



Pilot comments on why they experienced higher workload in the back seat:

Comments regarding operation of the MEP:

- The MEP operator usually has higher workload.
- MEP operator (has higher workload).
- Running the MEP is higher workload.
- As MEP operator, it requires a lot of attention.
- Back seat (had higher workload) because of working the majority of the MEP in this scenario.
- Current configuration places the MEP operator in the rear seat.
- The back seat was used as the MEP operator.
- More MEP operations (in the back seat).
- Because the back seat has to be able to communicate, ID the target and maintain airspace surveillance. All at the same time.
- The front seater just flies, the back seater was doing all the work.
- The individual not flying classifies and communicates and services while the front seat flew.
- More mission requirement in back seat
- Front seat responsible for obs avoidance, NAV, radio traffic. Rear seat threat location, ID, spot reports.
- It does take a lot of effort to fly point to point, the back seat scanning and reporting ARTY, weapons engagement. (all "inside" work).

**Significant at α .01

Comments regarding the TAS:

- Back seat needs NVG or some system to see outside the A/C when the TAS is used.
- TAS manual slew for scanning or viewing difficult.
- P (not on controls) needs vision to improve TAS operations.
- Rear seat should be able to see outside the aircraft even when the TAS is operated.
- Slew hook for TAS manual ops does not allow for any real TGT, ID or development. No azimuth, no target, and no range.
- Front seat primarily responsible for flying, obstacle avoidance, NAV. Rear seat all systems with TAS and NPVs.

Comments regarding labeling function:

- The labeling function is too slow.
- Need new labeling system for TGTS.
- Target labeling in TSD.
- Labels/Windows.
- TAS/Labeling/Windows requires high workload with eyes in almost all times.

Comments regarding radio communications:

- Manual entry of frequencies and grid locations to navigate with.
- Selecting radio requires visual verification (hands on). Radio frequency display position is far from center.
- Location of RFD makes it difficult to see and read. Need ability to see which of our five radios people are transmitting on to aid in situational awareness.

Comments regarding the CIK:

- B/S ops on CIK. The keyboard is cumbersome. I would like it in a normal typing configuration with the numbers in a numerical keypad configuration.
- The CIK is too slow.

Other comments:

- There needs to be another trigger for WPNS engagement.
- The heading tape should remain stationary. It can be confusing if you look down then back up and everything is moving. HSI indicators are hard to see. Both crew stations are looking inside while no one is focusing outside.
- Spot reports, difficult to separate targets destroyed from those not destroyed. Sometimes difficult to separate line and rotated targets.

<u>Pilot comments on why they experienced higher workload in the Front Seat:</u>

- FS only because of difficulty of cross checking dash displays with viewing out the window (HMD) and flying very low and fast.
- ASE display was difficult to view and avoid the terrain from F.S.

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REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final

4. TITLE AND SUBTITLE

Assessment of Crew Workload for the RAH-66 Comanche Force Development Experiment 1

5. FUNDING NUMBERS

AMS Code 622716
Project No. AH70

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARL-TN-183

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Crew workload was assessed during the RAH-66 Comanche Force Development Experiment (FDE) 1. The purpose was to determine if (a) the pilots experienced tolerable and comparable workload levels when flying the aircraft versus operating the mission equipment package (MEP), and (b) workload levels contribute to a need to "battle roster" Comanche pilots. Workload data were collected via the Bedford Workload Rating Scale and a cockpit controls and displays usability questionnaire.

Results of the assessment indicate that (a) workload was tolerable for the pilots, (b) workload was moderately higher for the pilots when they operated the MEP, and (c) there is no compelling need to prescribe battle rostering because pilots experienced only moderate differences in workload when they flew the aircraft versus when they operated the MEP.

14. SUBJECT TERMS

Army aviation
crew workload
RAH-66 Comanche
workload

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	